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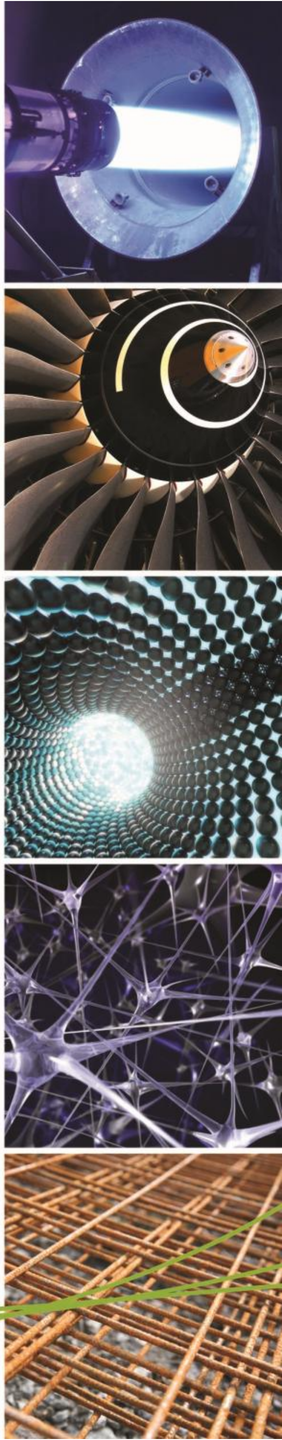
Prifysgol Abertawe

Advanced Structural Analysis

EGF316

Fatigue



Lecture Content

- Introduction
- Fatigue Testing
- Fatigue Limit
- Endurance Limit
- The Effect of Mean Stress
- Cumulative Fatigue Damage
- Examples

Introduction

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Fatigue and Fracture Mechanics is primarily concerned with the ***initiation*** and ***propagation*** of a crack or cracks in a material until a point is reached when the component or structure can no longer sustain the level of applied loading

Crack Initiation

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Where are cracks most likely to initiate?

Crack Initiation

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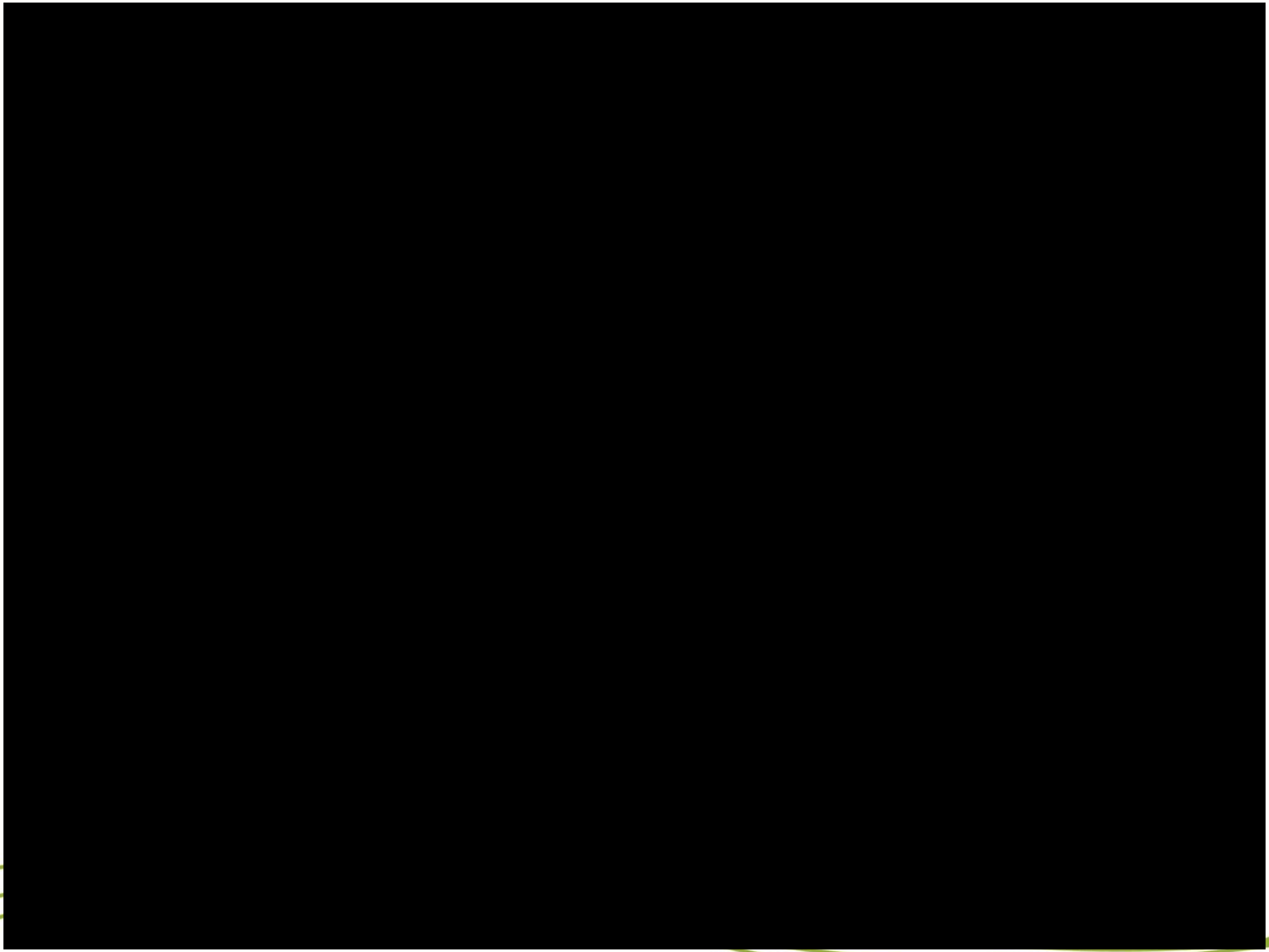
Where are cracks most likely to initiate?

Location(s) of stress concentration

Fracture failure



Fatigue failure

‘90% of all failures of metallic structures (aircraft, bridges, machine components etc) are estimated to be brought about by fatigue and 90% of all fatigue failures are due to lack of attention to design detail’

The Design Goal

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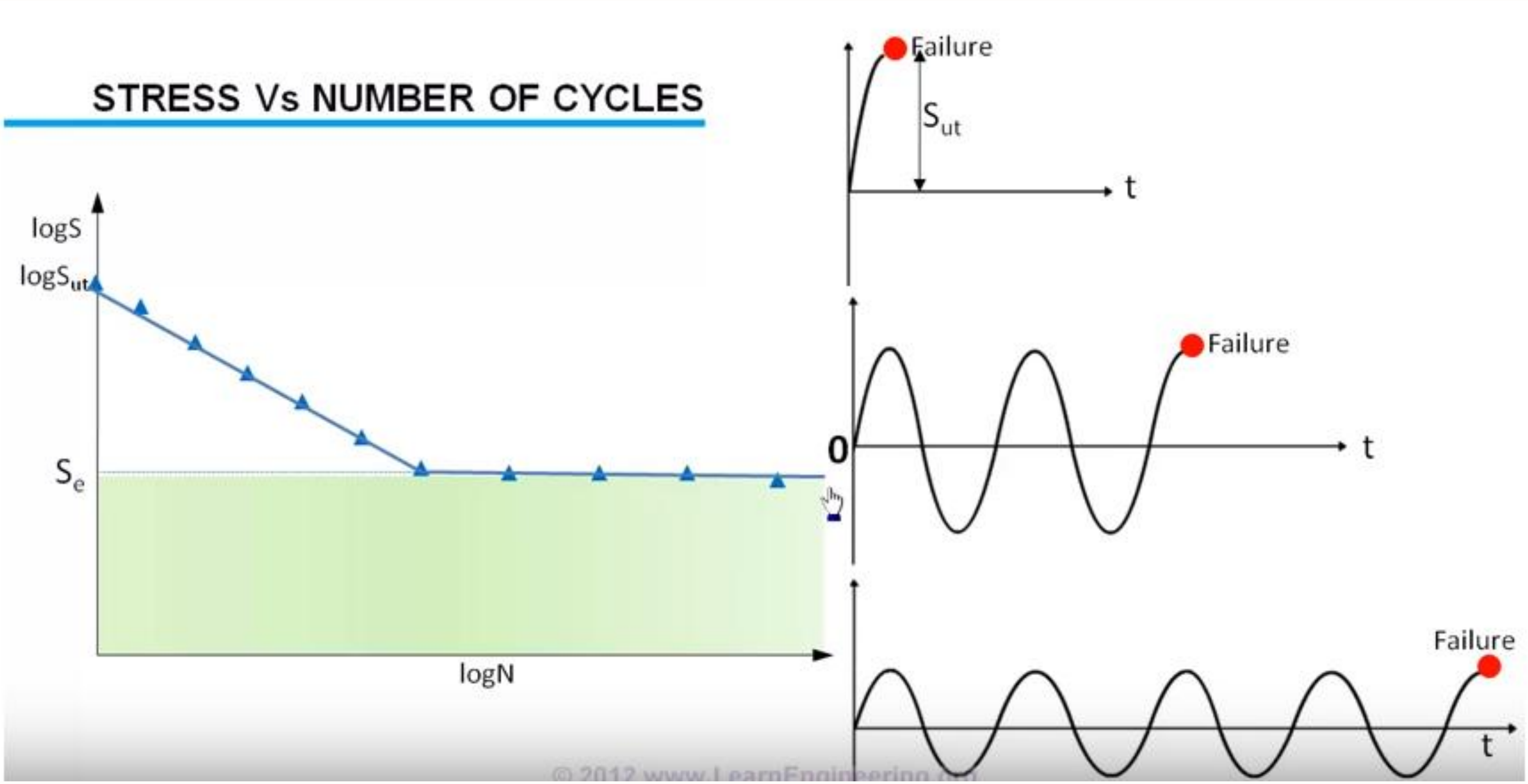
- To design to avoid fatigue failure
- To predict when failure is likely to occur

Fatigue loading

Loads are not always static. Often, they vary with time. For example,

- Wind and wave loading
- Reversed loading on a drive shaft
- Repeated bending of a crankshaft
- Pressure pulsations in pipework (water hammer)



Source: LearnEngineering YouTube Channel

Failure Testing – Wohler machine

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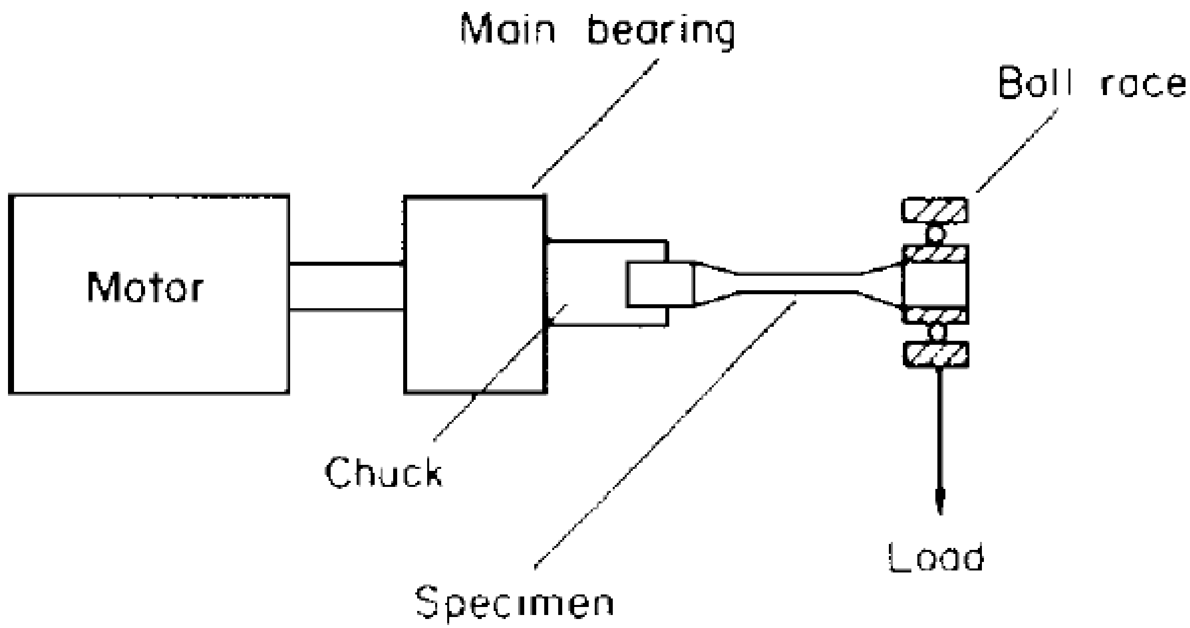

Failure Testing

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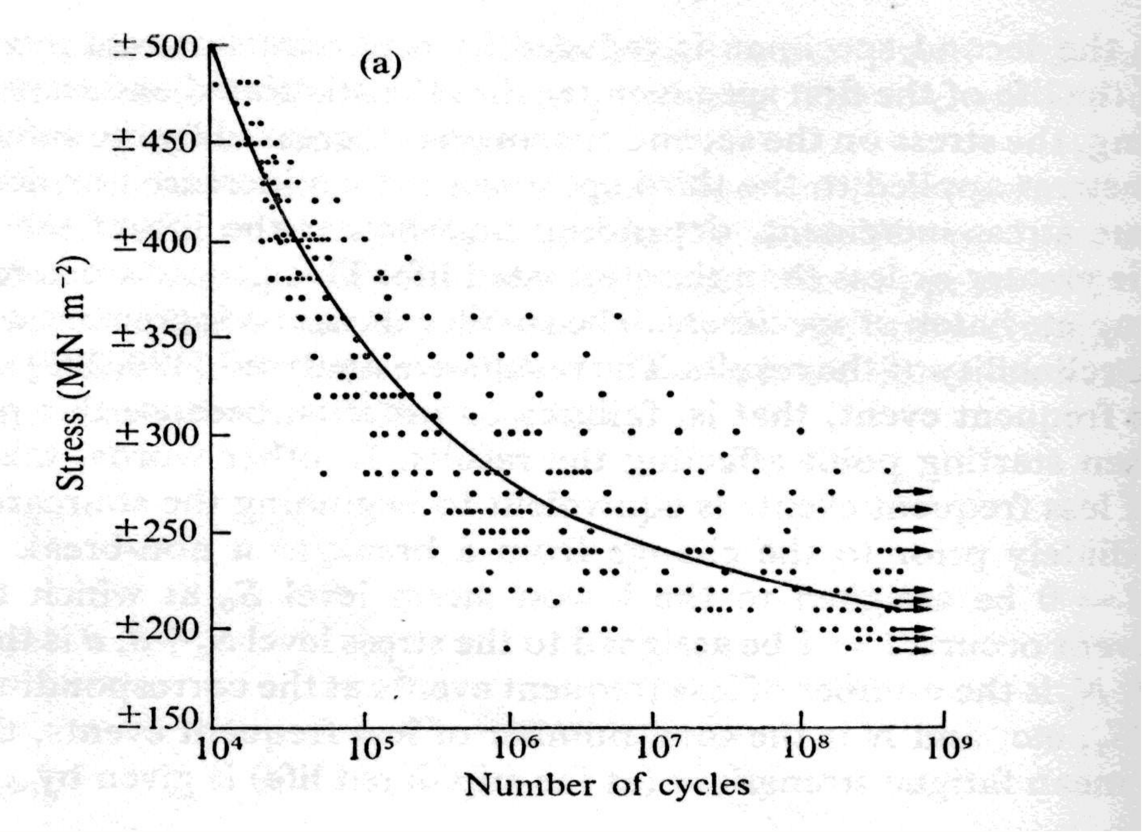
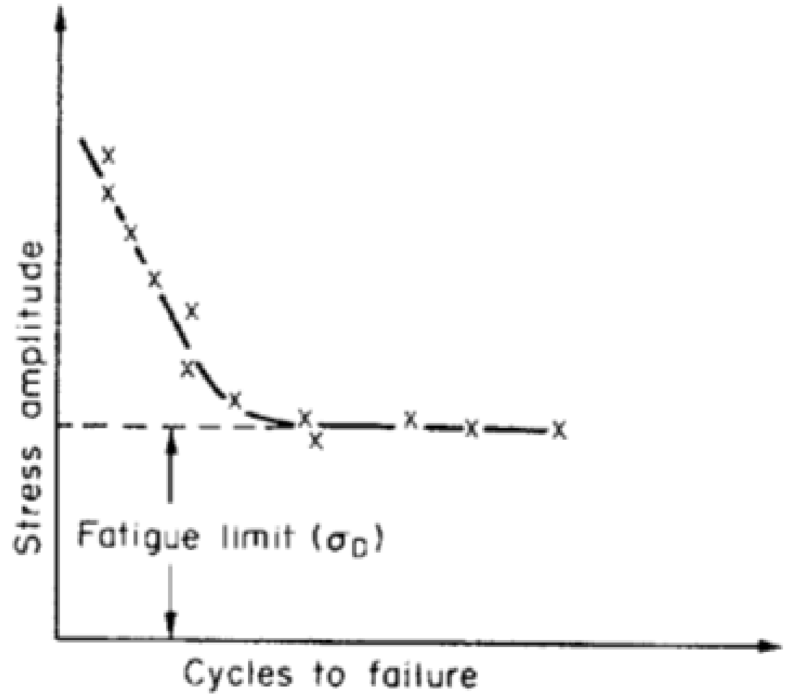
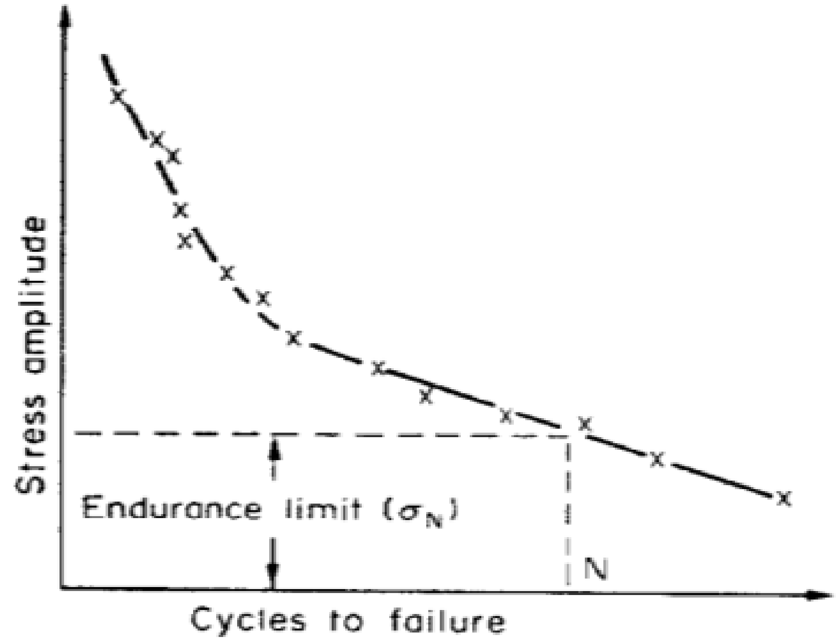
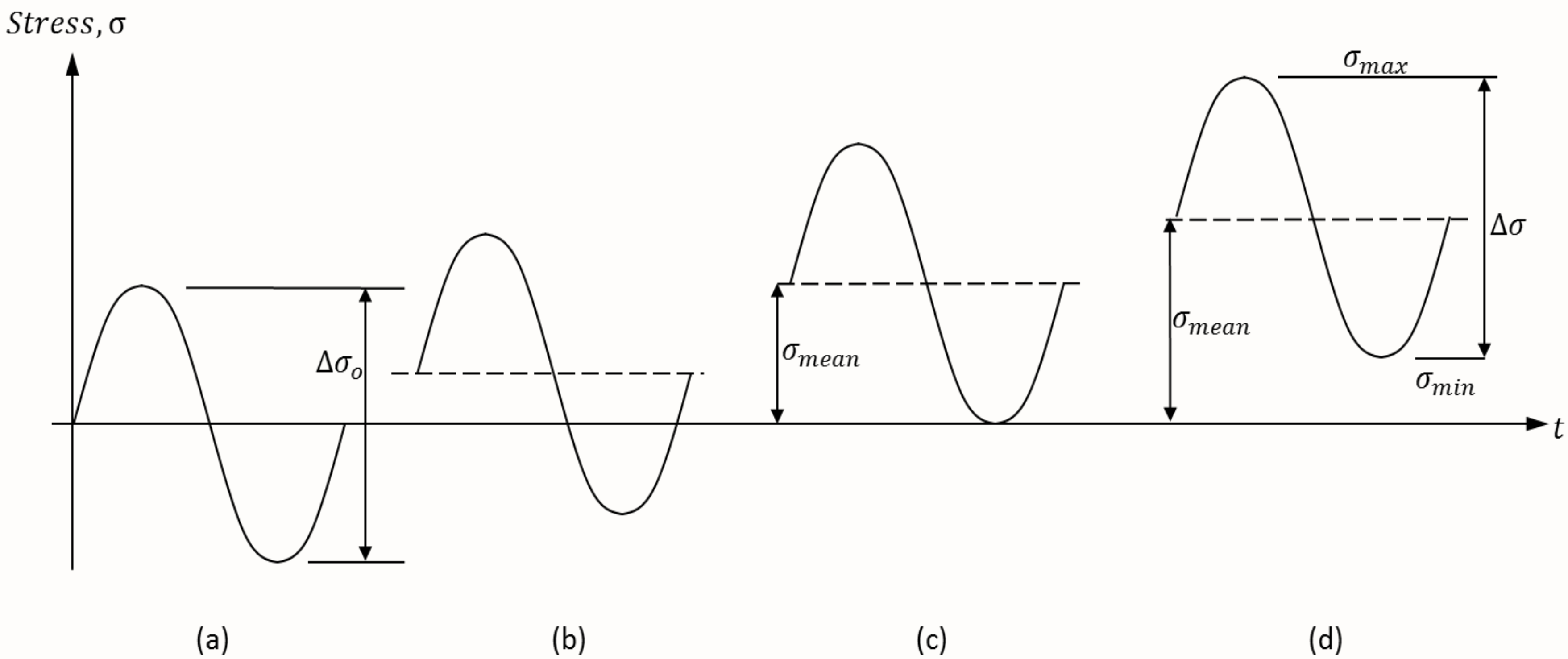


Endurance Limit





Fatigue life - Types of Cycles



Failure life - stresses

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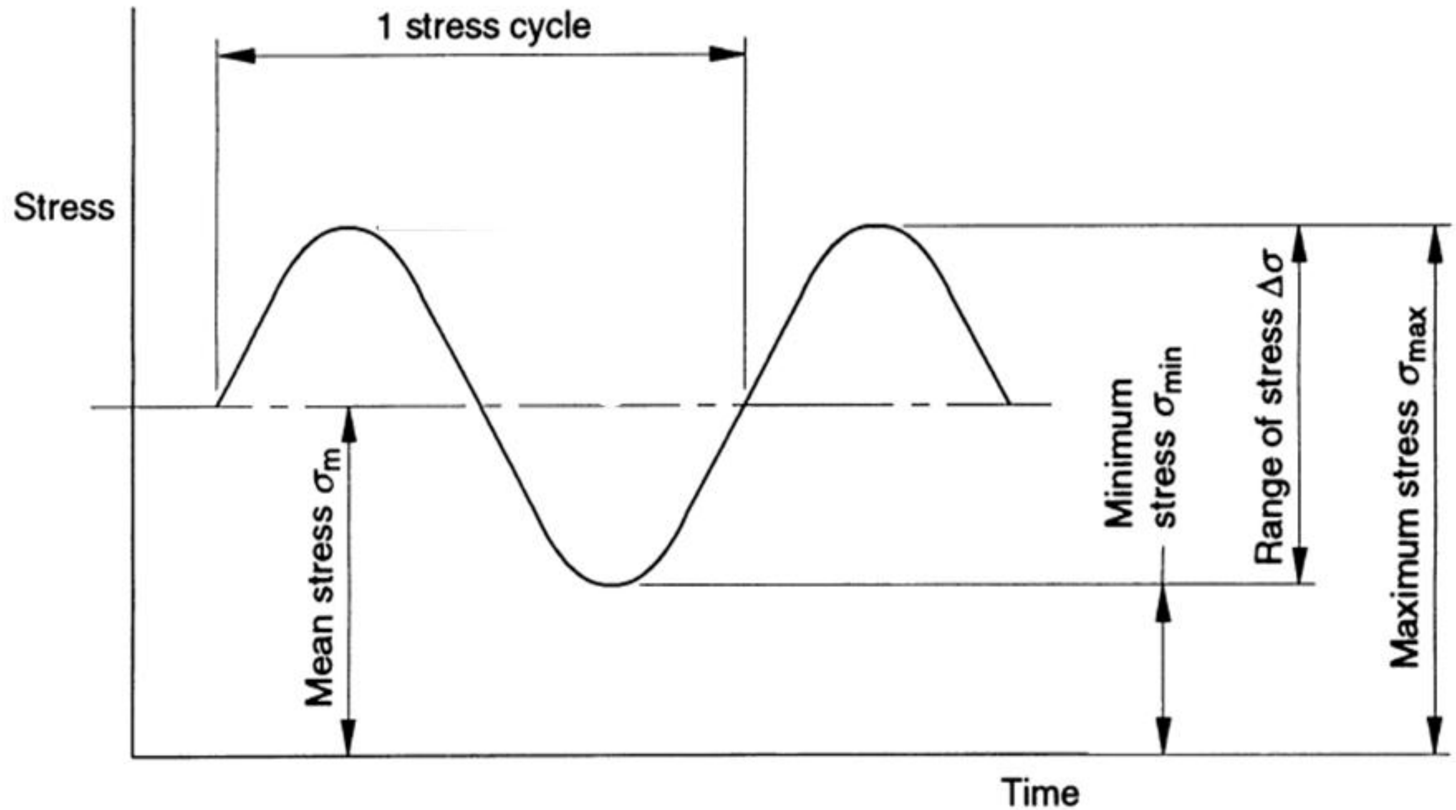

Fatigue Design Rules

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Goodman:

$$\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_u} = \frac{1}{FS}$$

Soderberg:

$$\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_y} = \frac{1}{FS}$$

Gerber:

$$\frac{FS * \sigma_a}{\sigma_e} + \left(\frac{FS * \sigma_m}{\sigma_u}\right)^2 = 1$$

Fatigue Design Rules

When FS=1

Goodman:

$$\sigma_a = \sigma_e \left[1 - \left(\frac{\sigma_m}{\sigma_u}\right)\right]$$

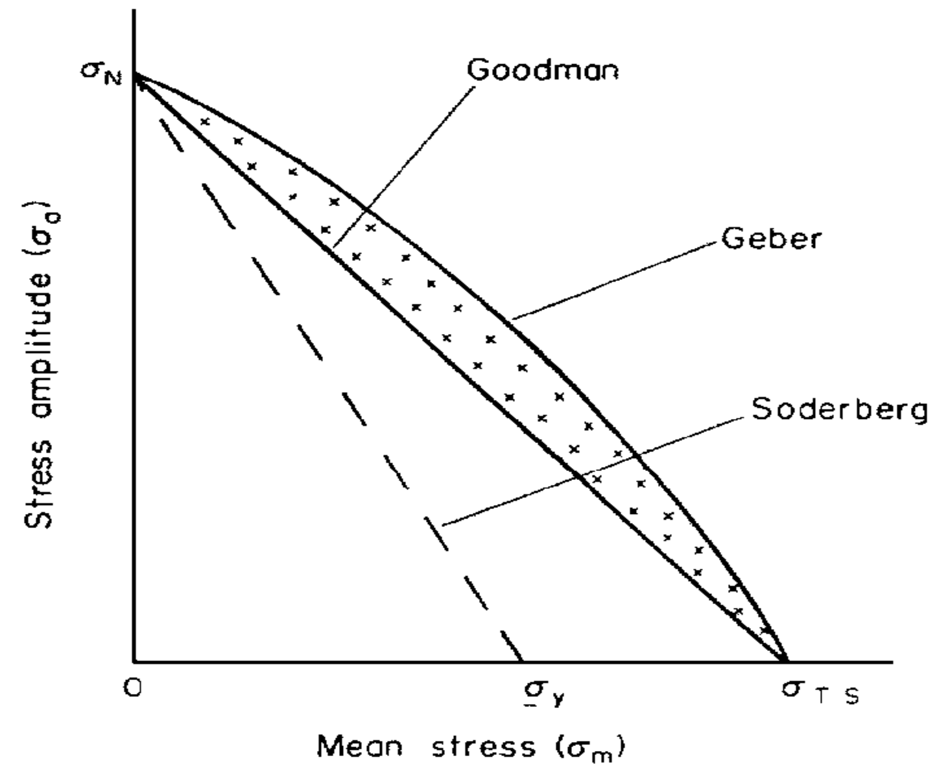
Soderberg:

$$\sigma_a = \sigma_e \left[1 - \left(\frac{\sigma_m}{\sigma_y}\right)\right]$$

Gerber:

$$\sigma_a = \sigma_e \left[1 - \left(\frac{\sigma_m}{\sigma_u}\right)^2\right]$$

Fatigue Design Rules



Most actual test data tend to fall between the Goodman and Gerber curves

Example 1:

The ultimate tensile strength of a low carbon steel is 870MPa and the yield stress is 380MPa. The fatigue limit, is 230MPa.

(i) Estimate the safe range of stress, for a repeated cycle based on the Gerber and Goodman equations

(ii) Estimate the safe range of stress, the maximum and the minimum stress for a fluctuating tensile cycle with a mean stress of 185 MPa, using the Soderberg equation

Example 2:

A steel shaft is subjected to a fluctuating axial load of +120kN and –20kN.

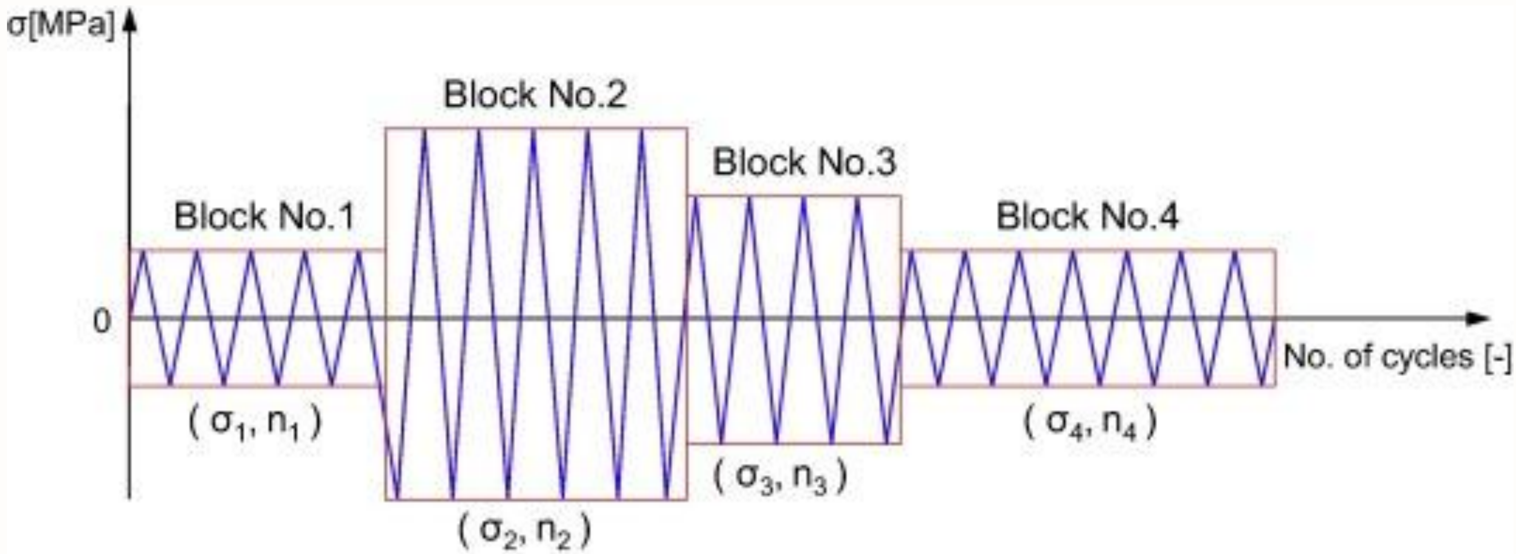
The shaft diameter is 25mm.

The reversed stress fatigue limit is 600MPa, the UTS is 400MPa and the yield strength is 200MPa.

Determine the maximum allowable stress range and therefore the factor of safety for the shaft according to Goodman, Gerber and Soderberg.

Cumulative Fatigue Damage

What do we do when the level of cyclic loading is not constant ie: it varies with time?



Miner's Linear Damage Rule

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} \dots\dots\dots\dots \frac{n_i}{N_i} = C$$

Where:

n is the number of applied cycles at a given level of stress
N is the maximum number of cycles for the applied stress
C is a constant in the range $0.7 \leq C \leq 2.2$

In general,

$$\sum \frac{n}{N} = 1$$

Example 3:

Cyclic bending stresses of 75, 60 and 40MPa are applied to a beam in a lifting machine.

If the portion of time spent at these three levels is 30, 50 and 20% respectively, estimate the working life, in days, when the machine operates continuously at 10 cycles per day.

Assume that the fatigue lives to be 10^3, 10^4 and 10^5 cycles at 75, 60 and 40MPa respectively.

Example 4:

A steel bracket used to support a rotating machine is subjected to variable stress amplitude high cycle fatigue loading.

An analysis of the stress frequency response over a period of 2000 cycles shows that the variable stress amplitudes can be divided into six blocks over that period, as shown in the following table.

Stress	130MPa	120MPa	70MPa	100MPa	200MPa	150MPa
Duration	700 cycles	400 cycles	350 cycles	200 cycles	250 cycles	100 cycles
No of cycles to failure (based on constant stress amplitude)	10^8	10^9	10^9	10^7	10^8	10^6

Example 4 (continued):

If it is assumed that the frequency response for each period of 2000 cycles follows the same form.

Using the constant stress amplitude versus number of cycles to failure data given, estimate the number of cycles to failure for the bracket, according to Miner’s linear damage rule.